Listing of Claims:

CLAIMS

1. (Currently Amended) A system for estimating the position, velocity and orientation of a vehicle, comprising:

- means for determining the components of two noncollinear constant unit vectors $\hat{g}_b, \hat{e}_b$ according to vehicle body axes, said means including:

- an Inertial Measurement Unit (IMU) including a group of at least three gyroscopes for measuring the angular velocity $\hat{\omega}_b(t)$ of the vehicle in body axes and at least three accelerometers located along the vehicle body axes to provide the specific force $\hat{a}_b$ in body axes;

- a magnetometer able to measure the Earth's magnetic field according to the vehicle body axes;

- static pressure and differential pressure sensors;

- two vanes to measure the angles of attack and side slip;

- an angular velocity acquisition and processing module configured to acquire the angular velocity $\hat{\omega}_b(t)$ and delay it to obtain $\hat{\omega}_b(t-\tau)$;

- a data acquisition and processing module configured to acquire the specific force $\hat{a}_b(t)$ measured by the accelerometers, the static pressure $\hat{p}_s(t)$ measured in sensor, the differential pressure $\hat{p}_d(t)$ measured in sensor, the angle of attack $\hat{\alpha}(t)$ measured in sensor, the angle of sideslip $\hat{\beta}(t)$ measured in sensor and the value of the Earth's magnetic field $\hat{m}_b(t)$ measured in the magnetometer, delay them and process them to calculate the true airspeed $\hat{\upsilon}(t-\tau)$, the air velocity in

body axes $\widehat{v}_b(t-\tau)$ as follows:

$$\widehat{v}_b = \begin{bmatrix} \widehat{\upsilon}\cos\widehat{\alpha}\cos\widehat{\beta} \\ \widehat{\upsilon}\sin\widehat{\beta} \\ \widehat{\upsilon}\sin\widehat{\alpha}\cos\widehat{\beta} \end{bmatrix},$$

the numerical derivative of the air velocity in body axes $\dot{\widehat{v}}_b(t-\tau)$,

the local gravity in body axes $\widehat{g}_b$ as follows:

$$\widehat{g}_b(t-\tau) = \dot{\widehat{v}}_b(t-\tau) + \widehat{\omega}_b(t-\tau) \times \widehat{v}_b(t-\tau) - \widehat{a}_b(t-\tau)$$

and the projection of the Earth's magnetic field on the horizontal plane perpendicular to local gravity $\widehat{e}(t-\tau)$ as follows:

$$\widehat{e}_b(t-\tau) = \widehat{m}_b(t-\tau) - \widehat{m}_b(t-\tau) \cdot \frac{\widehat{g}_b(t-\tau)}{|\widehat{g}_b(t-\tau)|};$$

- a GPS receiver ~~means~~ for determining the components of said noncollinear constant unit vectors $\vec{g}_t, \vec{e}_t$ according to the Earth's axes; wherein the data provided by the GPS are acquired, processed and used in the data acquisition and processing module to calculate said components $\vec{g}_t, \vec{e}_t$; ~~and~~

~~means for determining the three components of the angular velocity ω_b of the vehicle in body axes;~~

wherein the system comprises

- a module ~~means~~ for correcting said angular velocity $\widehat{\omega}_b$ with a correction u_ω and obtaining a corrected angular velocity $\hat{\omega}_b = \widehat{\omega}_b + u_\omega$;
- a module for integrating the kinematic equations of the vehicle receiving the corrected angular velocity $\widehat{\omega}_b$ as input and providing the transformation matrix $\hat{B}$ for transforming Earth's axes into vehicle body axes and the orientation of the vehicle in the form of Euler angles $\hat{\Phi}$;
- a synthesis module of the components in body axes of the two noncollinear constant unit vectors to provide an estimation of said noncollinear vectors in body axes $\hat{g}_b, \hat{e}_b$, where said estimation is calculated as follows:

$$\vec{g}_b = B\vec{g}_t$$
$$\vec{e}_b = B\vec{e}_t$$

- a control module implementing a control law to calculate said correction u_ω, where said control law is:

$$u_\omega = \sigma(\bar{g}_b \times \hat{g}_b + \bar{e}_b \times \hat{e}_b) \qquad [1]$$

where σ is a positive scalar,

such that by applying this correction u_ω to the measured angular velocity $\bar{\omega}_b$ and using the resulting angular velocity $\hat{\omega}_b = \bar{\omega}_b + u_\omega$ as input to the module for integrating the kinematic equations, the latter are stable in the ISS sense and the error in the estimation of the direction cosine matrix $\hat{B}$ and of the Euler angles $\hat{\Phi}$ is bounded.

2. (Previously Presented) The system according to claim 1, wherein said noncollinear unit vectors $\vec{g},\vec{e}$ are local gravity $\vec{g}$ and projection of the magnetic field on the plane perpendicular to gravity $\vec{e}$.

Claims 3 and 4 (Canceled).

5. (Currently Amended) The system according to claim 1 ~~3~~, wherein the system includes a Savitzky-Golay filter ~~(179)~~ where $\dot{\hat{v}}_b$, numerical derivative of $\hat{v}_b$, is calculated.

6. (Currently Amended) The system according to claim 1 including:

~~- means of acquiring data from a group of sensors located in the vehicle, providing position and speed according to Earth's axes P_t, V_t;~~

~~- means of acquired data from another group of sensors located in the vehicle, providing specific force $\bar{a}_b$ in body axes;~~

- a navigation module where the navigation equations of the vehicle are

integrated from the specific force $\hat{a}_b$ and the direction cosine matrix $\hat{B}$ to obtain calculated position and velocity ~~speed~~ in local axes and corrected in a Kalman filter to obtain estimated position and velocity ~~speed~~ in local axes.

7. (Currently Amended) A method for estimating the position, velocity and orientation of a vehicle comprising:

- calculating the components of two noncollinear constant unit vectors $\hat{g}_b, \hat{e}_b$ according to vehicle body axes from measurements of sensors located in the vehicle according to the body axes of the latter, said calculation comprising:

- measuring specific force $\hat{a}_b(t)$ in body axes, static pressure $\hat{p}_s(t)$, differential pressure $\hat{p}_d(t)$, angle of attack $\hat{\alpha}(t)$, angle of sideslip $\hat{\beta}(t)$ and the value of the Earth's magnetic field $\hat{m}_b(t)$;

- calculating the true airspeed $\hat{\upsilon}(t)$ from the differential pressure $\hat{p}_d(t)$ and static pressure $\hat{p}_s(t)$ measurements and from knowing the outside temperature at the initial moment T_0;

- calculating the air velocity in body axes as follows:

$$\hat{v}_b = \begin{bmatrix} \hat{\upsilon}\cos\hat{\alpha}\cos\hat{\beta} \\ \hat{\upsilon}\sin\hat{\beta} \\ \hat{\upsilon}\sin\hat{\alpha}\cos\hat{\beta} \end{bmatrix};$$

- delaying a time τ the angular velocity $\hat{\omega}_b(t)$, specific force $\hat{a}_b(t)$, magnetic field $\hat{m}_b(t)$ and air velocity in body axes $\hat{v}_b(t)$;

- calculating the numerical derivative of the air velocity in body axes $\dot{\hat{v}}_b(t-\tau)$;

- calculating the local gravity in body axes $\hat{g}_b$ as follows:

$$\hat{g}_b(t-\tau) = \dot{\hat{v}}_b(t-\tau) + \hat{\omega}_b(t-\tau) \times \hat{v}_b(t-\tau) - \hat{a}_b(t-\tau); \text{ y,}$$

- calculating the projection of the Earth's magnetic field on the horizontal plane perpendicular to local gravity as follows:

$$\hat{e}_b(t-\tau) = \hat{m}_b(t-\tau) - \hat{m}_b(t-\tau) \cdot \frac{\hat{g}_b(t-\tau)}{|\hat{g}_b(t-\tau)|};$$

- calculating the components of said noncollinear constant unit vectors $\vec{g}_l, \vec{e}_l$, according to the Earth's axes from measurements of sensors located in the

vehicle which provide position in ~~local~~ Earth-fixed axes;

- measuring the three components of angular velocity $\tilde{\omega}_b$ of the vehicle in body axes;
- correcting the angular velocity $\tilde{\omega}_b$ with a correction u_ω and obtaining a corrected angular velocity $\hat{\omega}_b = \tilde{\omega}_b + u_\omega$;
- integrating the kinematic equations of the vehicle, according to the corrected angular velocity $\hat{\omega}_b$ and providing the transformation matrix $\hat{B}$ for transforming the Earth's axes into vehicle body axes and the orientation of the vehicle in the form of Euler angles $\hat{\Phi}$;
- calculating an estimation of the components in body axes of the two noncollinear constant unit vectors $\hat{g}_b, \hat{e}_b$, where said estimation is calculated as follows:

$$\hat{g}_b = \hat{B}\vec{g}_t$$
$$\hat{e}_b = \hat{B}\vec{e}_t$$

- obtaining the correction u_ω by means of the control law:

$$u_\omega = \sigma(\tilde{g}_b \times \hat{g}_b + \tilde{e}_b \times \hat{e}_b) \qquad [1]$$

where σ is a positive scalar,

such that upon applying this correction u_ω to the measured angular velocity $\tilde{\omega}_b$ and using the resulting angular velocity $\hat{\omega}_b = \tilde{\omega}_b + u_\omega$ as input to the module for integrating the kinematic equations, the latter are stable in the ISS sense and the error in the estimation of the direction cosine matrix $\hat{B}$ and of the Euler angles $\hat{\Phi}$ is bounded.

8. (Previously Presented) The method according to claim 7, wherein said noncollinear unit vectors $\vec{g}, \vec{e}$ are local gravity $\vec{g}$ and projection of the magnetic field on the plane perpendicular to gravity $\vec{e}$.

Claims 9 and 10 (Canceled).

11. (Currently Amended) The method according to claim <u>7</u> ~~9~~, wherein $\dot{\hat{v}}_b$, the numerical derivative of $\hat{v}_b$, is calculated in a Savitzky-Golay filter ~~(179)~~.

12. A method according to claim 7 including:

~~- measuring position and speed in Earth-fixed axes P_t, V_t;~~

~~- measuring specific force $\hat{a}_b$ in body axes;~~

- integrating the navigation equations of the vehicle according to the specific force $\hat{a}_b$ and the direction cosine matrix $\hat{B}$ to obtain the calculated position and <u>velocity</u> ~~speed~~ in local axes and they are corrected in a Kalman filter to obtain estimated position and <u>velocity</u> ~~speed~~ in local axes.